Efficacy of UV-A LED for Germicidal Disfection of biofilm surface in mini splits, rev2

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Background

An independent literature review was performed to consider the efficacy of UV-A LEDs for the purpose of disinfection of biofilm fouling of mini splits

Introduction

Ultraviolet germicidal irradiation (UVGI) is a disinfection method that UV light to destroy or disrupt the life cycle of microorganisms. This is achieved by destroying and fundamentally altering their nucleic acids and DNA, so that they are no longer able to carry on critical cellular functions. The UV spectrum is commonly divided into UVA (400 to 315nm), UVB (315 to 280 nm) and UVC (280 to 200 nm) bands. The entire UV spectrum can kill or inactive many microrganis but traditionally, UVC has provided the most germicidal effect with 265 nm being the optimal wavelength (ASHRAE, 2008).

More Susceptible	Organism Group	Member Group
Vegetative Bacteria	Vegetative Bacteria	*Staphylococcus aureus*
		Streptococcus progenies
		Escherichia coli
		Pseudomonas aeruginosa
		Serratia marcescens
Mycobacteria	Mycobacteria	*Mycobacterium tuberculosis*
		Mycobacterium bovis
		Mycobacterium leprae
Bacterial Spores	Bacterial Spores	*Bacillus anthracis*
		Bacillus cereus
		Bacillus subtilis
Fungal Spores	Fungal Spores	*Aspergillus versicolor*
		Penicillium chrysogenum
Less Susceptible		*Stachybotrys chartarum*

Fig.1 General ranking of susceptibility of various organism groups to UVC inactivation with examples of species from each group (Martin Jr. et al, 2008)

UVGI is used in a growing variety of applications, such as food, air, biofilm surfaces and water purification. In buildings, they are used within air condition systems for improving Indoor Air Quality (IAQ) and in hospitals, they are used to mitigate Hospital Acquired Infections (HAI).

In germicidal applications in food processing, manufacturing, low volume water treatment and medical service, low pressure Mercury (Hg) lamps emitting approx. 93% of their output at 254 nm have traditionally been utilized. Recent improvements in UV-LED flux density, stability and lifetime hours have increased the viability of UV-LEDs as a replacement for traditional UV light sources such as mercury arc lamps, arch lamps, hot and cold cathode lamps and grid lamps. UV LEDs are more environmentally friendly as they do not contain harmful mercury, do not produce ozone and consume less energy. Wavelength tunability of UV LEDs is achieved by adjusting the material of the semiconductor.

In spite of their advantages, UV LEDs aren't a panacea. For example, traditional lamps have a far greater fluence than their UV LED counterparts. In applications such as water treatment plants, medium or low pressure UV lamps are preferred because they are capable of high intensity germicidal UV. The number and cost of LED or Hg lamps required to meet WTP application intensity levels would be unfeasible.

In 2019, the electrical-to-UVC conversion efficiency of UV LEDs was still lower than that of mercury lamps. UV-C LEDs must be carefully chosen for the application. UV LEDs don't necessarily last longer than traditional germicidal lamps, but have more variable engineering characteristics, making them better suited for short-term "on-demand" operation. For such "on-demand" applications, the semiconductor properties of UV-C LEDs allow them to be cycled on/off tens of thousands of times with no perceivable degradation. Therefore, they can achieve a longer installed time than a traditional germicidal lamp in intermittent use. LED degradation increases with temperature, forward current and material , while filament and HID lamp output wavelength is dependent on temperature. Engineers need to match these tradeoffs to the design requirements: higher output and faster degradation or lower output and a slower decline over time.

UV-A LEDs for Biofilm Disinfection Application

Since 2008, the American Society of Heating, Refrigeration and Air Conditioning (ASHRAE) has included ultraviolet germicidal irradiation, or UVGI, in its handbooks. The subsequent awareness has created a continuously growing demand for UV in virtually every stage of construction including medical, commercial, residential, and retrofit applications. Bio-fouling of coils, particularly in commercial buildings, reduces effciency. UV at the 270 nm wavelength is a proven and cost-effective solution for both IAQ and mold disinfection.

A corporate sponsored study was conducted to compare efficacy of 405 nm to 275 nm for disinfection application (Bolton, 2019). The literature review concluded that while 405 nm can achieve inactivation of many bacterias, the fluences are very high. Comparing 1 log inactivation, 405nm requires 60-120 J/cm^2 while 254 nm requires approx. 0.002 J/cm^2.

The report concludes that long exposure times required to achieve the required fluences would require a large array of 405 nm LEDs and may not work because the balance between rate of coil contamination may exceed rate of inactivation from the 405 nm LED array.

One potential way to overcome this is by using pulsed low frequency LED irradiation. Experiments have been performed with positive results in UVA band: 315-400nm (Li et al., 2010) and 365nm (Yumoto et al., 2010). Experiments with *Candida albicans* or *Escherichia coli* biofilms demonstrated that with 5 minutes irradiation, over 90% of viable micro-organisms in biofilms had been killed, and pulsed irradiation (1-1000 Hz) had significantly greater germicidal ability than continuous irradiation. Pulsed irradiation (100 Hz, 60 min) almost completely killed micro-organisms in biofilm (>99·9%), and 20 minute irradiation greatly damaged both microbial species (Yumoto et al., 2010).

UV-A LED experiments with 365 nm have been performed for air disinfection of *Escherichia coli*, *Serratia marcescens* and *microccus luteus*. Gadelmoula et al. (2009), observed 99.9% reduction of *E.coli* populations after 75 min of exposure to high power UVA-LED under constant current 915.3 W/cm^2) or pulsed current 91.3W/cm^2). In an extended study, UVA-LED reduced cell viability in aerosols of S. marcescens and *M. luteus* by more than 90% after 10 min of constant exposure (37.2 W/cm^2) or a pulsed protocol (7.4 W/cm^2).

Synergistic effects of combining UV-A and UV-C wavelengths

Research at UV-LED technology leader, Phoseon Technology has demonstrated that the combination of 275nm UV-C and 365 nm UV-A has a reinforcing effect on inactivation of Rnase A, an enzyme harmful to the upper respiratory system and mucous membrane, by destabilizing its reaction pocket. These two wavelengths work together synergistically to completely inactive Rnase A faster and with greater efficacy than either wavelength can alone. It is a novel way to irreversibly inactive Rnases on surfaces (Pasquiantonio & Hoge, 2019). This combination can also be used to disinfect. In tests using a commercial 365nm UV-A ceiling fixture, the device was found to reduce pathogens on medical equipment and provide continuous low-level decontamination of surfaces by reducing bacteria and viruses. However, it was not effective in reducing *Clostridium difficile* spore (Livingston et al., 2019). *Clostridium difficile* is a spore that constitutes a continuing problem in healthcare facilities due to its transmission on contaminated surfaces. In contrast, using a combination of high intensity 275nm and 365nm UV LEDS resulted in a >5 log (5.79 log) reduction of *Clostridium difficile* spores on a surface in <30s, consistent with the synergistic effect of this combination in irreversibly inactivating RNase A. This demonstrated that targeting protein stabilization and functional groups is a novel approach to spore inactivation on surfaces (Pasquiantonio & Hoge, 2019). 1018 72nd Avenue NE, Calgary, Alberta Canada, T2E 8V9

References

ASHRAE Handbook (2008) – HVAC Systems and Equipment, Chapter 16

Bolton, J. R. (2019) *The disinfection efficacy of 405 nm light*, study for PremierOne Products, Inc.

Gadelmoula, M. et al. (2009) *Suitability of ultraviolet (A)-light emitting diode for air stream disinfection* J Med Invest., Aug: 56(3-4):150-6

Li, J. et al. (2010) *Enhance germicidal effects of pulsed UV-LED irradiation on biofilms* Journal of Applied Microbiology 109, 2183-2190

Livingstone et al. (2019) Efficacy of an ultraviolet-A lighting system for continuous decontamination of health care – associated pathogens on surfaces. American Journal of Infection Control, Available online Sept 3, 2019. https://www.sciencedirect.com/science/article/pii/S0196655319307461 Accessed Nov 28, 2019.

Pasquiantonio & Hoge (2019) *Non-laser Light Sources: Ultraviolet LEDs illuminate the scientific landscape: With differences in spectral distribution, power level, and regulatory issues, UV LEDs challenge mercury arc lamps for disinfection, chromatography, and fluorescence imaging applications.* https://www.laserfocusworld.com/lasers-sources/article/14068301/ultraviolet-leds-illuminate-the-scientific-landscape , Accessed Nov 28, 2019.

Yumoto, H. et al. (2010) *Enhanced germicidal effects of pulsed UV-LED irradiation on biofilms* Journal of Applied Microbiology, 109(6):2183-90